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<p>(54) Title: SIMPLIFIED DUPLEX PROCESSING OF NICKEL ORES AND/OR CONCENTRATES FOR THE PRODUCTION OF FERRONICKELS, NICKEL IRONS AND STAINLESS STEELS</p> <p>(57) Abstract</p> <p>Traditionally, processes to produce ferronickel, nickel iron and stainless steel are excessively multisteped, energy consuming, have refining difficulties and result in the formation of a slag, which cannot be usefully exploited as an aggregate in road material or in concrete. All of these drawbacks contribute to high manufacturing costs. These disadvantages can be overcome by using a direct smelting procedure, followed by a refining step. The source material consists of a nickel bearing ore and/or concentrate, together with an iron source as make up material, which is charged into a bath smelter (50) operating in a reduction/oxidising mode, continuously or intermittently. A reducing slag (57) containing carbonaceous material is formed over molten metal alloy (55), and oxygen (60, 61) is blown through tuyeres (58, 59) into the carbonaceous slag (57) to produce reducing gas and the space above the slag (57) to oxidise any excess carbon monoxide, so that a quiescent slag layer (56) exists between the turbulent slag layer (57) and the molten metal layer (55). Reduction to metal droplets occurs in the upper slag layer (57) and these percolate down through quiescent slag layer (56) to metal layer (55), both of which are siphoned or tapped off, as they fill to capacity. Mineral feed may consist of dried and/or calcined ores and/or concentrates of nickel sulphide and/or nickel laterite with/without iron ore and optionally chromite as a source of chromium. Fluxes such as calcium oxide are added to maintain a basic slag, which is kept fluid at the elevated temperature range of 1700 °C to 2000 °C. The second refining and finishing step is carried out in an argon oxygen decarburiser and/or a converter.</p>			

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**SIMPLIFIED DUPLEX PROCESSING OF NICKEL ORES AND/OR CONCENTRATES FOR THE PRODUCTION OF FERRONICKELS, NICKEL IRONS AND STAINLESS STEELS.****Field of the invention**

This invention relates to the processing of minerals containing nickel and iron to produce metal and in a particular non-limiting aspect relates to the production of stainless iron/steel products from minerals containing nickel and iron.

**Background of the invention**

In conventional processes for treatment of mined nickel bearing sulphide ores, the nickel bearing ore which typically contains 0.5% to 4% by weight nickel is normally subjected to a pre-treatment step to produce a concentrate. Typically, the pre-treatment step involves sulphide ore flotation and the concentrate formed by this step may typically have a nickel content in the region of 4%-25% by weight of nickel metal. The sulphide ore being treated may contain a nickel source in the form of pentlandite and/or violarite which may be mixed with a range of gangue materials such as pyrite, pyrrhotite, serpentine, talc, and olivine. The gangue materials with nickel ore may include arsenic, selenium, copper cobalt, fluorine, chlorine, silica, aluminium oxide, iron, magnesium oxide and calcium oxide and complex silicates and/or sulphides of these minerals.

The sulphur containing nickel concentrate may be subjected to a further treatment step such as an oxidation smelting step to produce a nickel sulphide matte and slag, heat for the process being generated by the oxidation of the sulphur containing minerals in the concentrate and by adding coal, oil or gas, oxygen and electrical power to produce sulphur dioxide, carbon monoxide and carbon dioxide gases. The nickel matte (typically 40% to 48% nickel) is tapped from the smelter and may be subjected to further oxidation via converting to give a higher grade nickel matte (typically 64 to 72% nickel) which is separated from any iron oxide and other oxidised minerals produced as a slag. The iron oxide and other waste by-products of the oxidation processes are generally discarded as slag or recycled back to the smelter. The presence of magnesium compounds in the slag above about 8% can cause significant difficulties in operating the typical nickel sulphide flash smelter. Additionally the presence of arsenic and selenium in the matte may cause significant difficulties in refining the matte to acceptable nickel metal specifications.

This high grade nickel matte may contain mixtures of cobalt, nickel and copper which are ultimately separated by hydrometallurgical and/or electrowinning process to give separate copper, nickel and cobalt metals in near pure form.

The nickel may then typically be combined with steel and other additives such as ferro chrome, ferro nickel etc. in an electric arc furnace to produce a stainless steel alloy.

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The slag produced in the initial oxidation and converting steps, may need to be treated to recover valuable metals retained in the slag. After this optional metal recovery process the slag is likely to be of no value and it must be disposed of in an environmentally and economically acceptable manner.

In another conventional process for the treatment of nickel bearing limonitic laterite and oxide ores (typical nickel content 1% to 3% by weight), the ores may be subjected to an acid leach (typically sulphuric acid under pressure) followed by other process steps to effect nickel separation and refining to near pure metal. Alternatively some of these laterite ores (e.g. saprolite) may be prepared by roasting, calcining/pelletising/converting/agglomeration followed by a electric furnace reduction smelting with coal or coke and electrical power etc (e.g. converting) to produce ferro-nickel.

Whilst conventional processes of the type discussed above typically give a satisfactory nickel product which can be used to make stainless steel, the number of processing steps and the difficulties in handling, high levels of deleterious minor elements such as but not limited to magnesium, phosphorous, arsenic and selenium compounds involved in the production of nickel from nickel sulphide ores and finally the production of stainless steel are significant factors in the cost and quality of the ultimate stainless steel product. Furthermore, such processes result in a material of value in the production of stainless steel, i.e. iron being discarded. In addition, the slag produced by the process often has characteristics which make it unsuitable for inclusion as an aggregate in road-building operations or concrete generally and costs are incurred in arranging its disposal.

The traditional stainless steel process uses a mix of raw materials being some or all of the following, scrap stainless steel, scrap steel, ferro nickel, nickel metal, ferro chrome, ferro silicon, ferro manganese. These materials are typically melted in an electric arc furnace, and then refined in one or more stages using refining furnaces such as convertors, hydrogen vacuum degassing or argon oxygen decarburising furnaces. The refining steps are necessary to obtain the desired product chemistry, e.g. the reduction of carbon down to very low levels, the part or full elimination of hydrogen from the metal and the elimination of typical impurities such as sulphur, selenium and phosphorous. The hot refined metal is then typically cast into slabs, billets or hot rolled coil.

Thus, there is a need for a process which has the potential to be more commercially attractive by reducing the number of steps involved in processing to stainless steel (such as no refining and matte production of ferro nickel via electric furnaces) and in handling undesirable levels of magnesium or arsenic and selenium compounds and which may make use of materials such as iron which are normally generated as waste by conventional processes in a useful and cost effective manner.

## 3.

In the invention described in this specification, the main metal feed materials required to produce stainless steel may simply be nickel sulphide and/or laterite and chromite which cannot be directly used in the traditional process. The crude metal may then be subjected to normal refining in an AOD furnace and casting operations or granulation etc. Thus there should be no necessity for an electric arc furnace or scrap steel, and/or scrap stainless steel etc although these materials could be used depending on economics and availability in the manufacture of stainless steel.

**Disclosure of the invention**

In one aspect the invention provides a process for the treatment of a mineral feed containing nickel and iron including the step of smelting the mineral feed under reducing conditions to produce a metal product containing nickel and iron.

More particularly the invention provides a method for the reduction of a mineral feed containing a nickel bearing ore and/or concentrate and an iron source in a single smelter, to produce a metal alloy product containing both nickel and iron metal including the steps of:-

- (i) adding the feed to a bath smelter;
- (ii) forming a slag layer containing carbonaceous material in the bath smelter above a layer of metal alloy product;
- (iii) bubbling oxygen containing gas directly into the slag layer to form a bubbled region of slag above a relatively calm slag region;
- (iv) directing oxygen containing gas into the bath smelter above the bubbled slag for post combustion of gases exiting from the slag layer;
- (v) maintaining reducing conditions in the slag layer whilst causing formation of metal droplets therein; and
- (vi) allowing the droplets to drop through the slag layer to accumulate as a layer of metal alloy product containing both nickel and iron beneath the slag layer.

Preferably the components of the mineral feed are chosen to provide a metal product which is ferro-nickel, nickel iron or stainless steel:

A number of preferred alternative approaches to and aspects of the performance of the method are summarised below:-

- (i) A mineral feed including a dried and/or calcined concentrate is reduced to produce ferro-nickel or nickel iron.
- (ii) Iron ore (which may be dried) is mixed with a dried and/or calcined nickel sulphide concentrate to provide a mineral feed. The mineral feed is then reduced to produce nickel-iron or ferro-nickel.
- (iii) Iron ore is mixed with a dried and/or calcined nickel sulphide

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concentrate and a nickel laterite ore (which may also be dried and/or calcined) to provide a mineral feed. The mineral feed is then reduced to produce nickel-iron or ferro-nickel.

(iv) A nickel bearing sulphide concentrate and laterite ore are mixed and/or dried or calcined to provide the mineral feed. The feed is then reduced to produce nickel-iron or ferro-nickel.

(v) A nickel laterite by itself or mixed with iron ore is used to provide the feed. The feed is then reduced to a nickel iron or ferro nickel. The feed may be dried prior to reduction.

(vi) Chromite ore may be dried and added to the mineral feed defined for (i), (ii), (iii), (iv) or (v) and is reduced to ferro chrome, either with the heated nickel bearing ores, or in a separate bath smelter or in a separate electric furnace which uses power from the bath smelter waste heat. The mineral feed is then reduced to produce a rough grade of stainless steel.

(vii) The ferro chrome, ferro nickel and/or nickel iron from (i) to (v) above may be further refined by converting and/or AOD processing to produce the desired grade of stainless steel or ferro-chrome, ferro nickel or nickel iron. These steps will help to remove undesirable elements such as sulphur, hydrogen, selenium etc and reduce carbon down to the very low levels required for stainless steel.

(viii) Flux materials such as calcium oxide are added to the bath smelter to assist in maintaining a fluid slag.

(ix) The slag temperature may be elevated above those normally required for making pig iron from 1400°C to 1600°C to 1700°C to 2000°C to assist in maintaining a fluid slag.

(x) The ability to run high temperature fluid slags enhances the ability to blend products in the post smelting steps in order to meet market specifications rather than via a complex pre-treatment step at the beginning of the process because of the need to maintain low fluid slag temperatures.

The proportion of nickel in the mineral feed may be adjusted to ensure that the metal alloy product preferably includes at least 1% nickel by weight but lower grade feeds can still be used. More preferably, the proportion of nickel in the metal alloy product to be produced is at least 5% by weight and more preferably at least 8% by weight and even as much as 15% to 35% by weight or more depending on the product specification. The objective is to end up with the correct percentage of nickel for the desired stainless steel product. Nickel in metallic ferro nickel, mineral or other suitable chemical or metal form may be added to the feed to increase the proportion of nickel reporting to the metal

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product. Typically the nickel will be present in the feed as a calcined sulphide concentrate and/or as a nickel laterite which optionally may have been dried or calcined. However a non-calcined and/or dried nickel feed may in some circumstances be used e.g where the sulphur is to be captured with the emissions from the smelting step of the process.

The feed may include magnesium compounds. The magnesium compounds may be in the form of talc which may be bound into complex sulphide/silicate compounds with other elements. The magnesium compounds may proportionately comprise as much as 10% and even more than 15% by weight of the mineral feed. It is noted that conventional flash smelting of nickel sulphide concentrate bearing feeds using smelting under sulphide oxidising conditions is generally commercially difficult or unviable when there is a high magnesium content in the mineral feed i.e. generally in our experience about 8% in the flash smelter slag or 12% in the bath smelter. This is because the slag freezing temperature and viscosity rises making the furnace increasingly difficult to operate because the molten slag and matte do not adequately flow. As a result, extra care is taken to decrease magnesium in the feed e.g. in the concentrate, but this process often results in a reduction in nickel recovery in the sulphide concentrate in the flotation step. Under the conditions of Applicant's invention, it is possible to operate with relatively high levels of magnesium because the bath smelting process herein can operate at much higher temperatures (i.e. 1500°C to 2000°C vs 1200°C to 1400°C for the conventional flash smelting) at which temperatures viscosity for usual slag compositions is significantly reduced and the slag flows freely from the furnace. This means that the tight control of slag chemistry otherwise required at lower temperatures is significantly alleviated. See diagrams for the  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{SiO}_2$ ,  $\text{MgO}$  systems to illustrate this point in Figures 6 and 7. Because arsenic and selenium report substantially to the slag and fume (typically 75%) in applicant's process, in contrast to the oxidising conditions of flash or bath smelting where most of the arsenic and selenium report to the nickel matte product, the difficulties associated with ores bearing arsenic and selenium may be substantially reduced.

The mineral feed may include a concentrate of a nickel bearing ore. Generally speaking it may be a dried calcined flotation concentrate. It may include a blend of a plurality of ores and/or concentrates. Alternatively, it may only include a single sourced dried calcined concentrate. Suitably, the mineral feed will not include substantial amounts of copper, as copper can cause embrittlement of the metal product. Preferably, the copper content of the feed will be such that the metal product includes less than 0.5% by weight of copper, more preferably less than 0.2% by weight of copper and even more preferably less than 0.05% by weight of copper. Alternatively, the copper nickel weight ratio in the mineral feed may be less than 1:18 more preferably less than 1:50. In situations where

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one or more of the components of the mineral feed include proportions of copper higher than those preferred, the other components of the feed may be selected for low copper content to ensure that the overall blend of components forming the mineral feed yield a metal product having a copper content within the preferred limits.

The mineral feed may include a solid oxide and/or carbonate residuc derived from leaching of a nickel bearing ore. The nickel bearing ore may be a nickel laterite. Leaching may be carried out under conditions which result in a small or significant portion of the nickel reporting to the solid residue. Similarly, the leaching conditions may be such as to result in a small or a substantial proportion of iron reporting to the residue. The leaching may remove cobalt, copper or any other unwanted materials from the ore. Leaching may suitably be carried out with acid. The acid may be sulphuric acid. Leaching may be carried out at superatmospheric pressure. Pressure may be raised to reduce the rate of dissolution of iron ore and alumina. The residue may be combined with one or more nickel bearing concentrates to provide a primarily iron rich mineral feed suitable for practising the invention. The nickel bearing concentrates may be calcined to remove sulphur prior to being combined with the residue.

A source or sources of iron may form a component of the mineral feed or ore used to provide the mineral feed. The iron source or sources may include metallic iron, steel, iron oxide, iron ore, chrome ores, charge chrome, nickel ores and concentrates, scrap nickel iron, scrap stainless steel, nickel and/or chrome bearing laterites and pyrite, pyrrhotite or mixtures thereof which may be calcined. Preferably the mineral feed contains sufficient iron to represent at least 50% by weight of the metal product produced by the process for a ferro nickel product, more preferably, at least 70% by weight of the metal product for a stainless steel or nickel iron product.

A source of chromium may form a component of the mineral feed. The chromium source may include chrome-iron oxides such as a laterite chrome, chromium metal, charge chrome (ferro-chrome) chromite and/or mixtures of these. Where chromium forms a significant component of the mineral feed, the level of chromium in the feed may be adjusted to ensure that it represents at least 2%, more preferably 2% to 35% by weight of the metal product. More preferably it may represent 15% to 30% by weight of the metal product.

Processing additives such as fluxes etc may be added to the mineral feed in a smelting furnace. Alternatively, they may be mixed with the mineral feed prior to processing in the smelting furnace. Such additives may include limestone, dolomite or other flux material and/or silica and any other minerals such as ferro silicon and ferro manganese as required for the efficient handling or production of slag and/or desired specifications for useful products such as stainless steel.

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An energy source such as coal, coke, coal char, petroleum coke or coke breeze must be added to the furnace either directly or by a mixture with the mineral feed and/or via the tuyeres and/or split between the tuyeres and top feeding equipment. Some of the tuyeres might in some circumstances use a neutral gas such as nitrogen to deliver carbonaceous material to the melt to promote the reduction reaction. It is the fixed carbon in the source of carbon which is the primary energy and fuel source driving the reduction reaction. The preferred form of carbonaceous material will have been processed to remove most of the moisture and volatiles to provide char, coke, petroleum coke or coke breeze.

The absence of water maximises the heat released by the conversion of carbon to carbon monoxide and carbon dioxide and minimises carbon consumption. Combustion oxygen is added to the furnace. The combustion oxygen is added to the slag phase. It is also added above the slag phase. By combustion oxygen we mean a gas containing at least 60% more preferably at least 80% and most preferably about 95% or more oxygen (by volume).

The gas added above the slag phase should preferably contain at least 90% oxygen to assist combustion of carbon monoxide and carbon with generation of heat, a significant proportion of which is captured by the slag, hence promoting the reduction processes by providing the exothermic energy required to offset the endothermic consumption of energy in the principal reduction of nickel and iron to metal and/or metal alloys.

The mineral feed may be subjected to a pre-treatment step prior to smelting in the furnace. The pre-treatment may include a drying step and/or a calcining step to drive off sulphur and water or crystallisation. The calcined mineral feed may be transferred directly to the smelting furnace to save heat.

Examples of typical nickel/iron bearing sulphide ores which may be used to provide the mineral feed include pentlandite and violarite. Ores containing these minerals are obtainable from various sources such as Mount Keith and Leinster in Australia. Representative analyses of sulphide concentrates of these ores are shown in Table 1 in the next page. These concentrates are particularly suitable for the practice of the invention because of their relative low copper content. They may also be blended with ores or concentrates from other areas having higher copper contents to give an overall blended mineral feed with a copper content at an acceptable level. In particular they may be blended with laterites, Table 2 showing a typical laterite analysis for the saprolitic, limonitic and transitional laterite ores typically found in a laterite orebody.

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TABLE I  
**MT KEITH CONCENTRATE**  
 (3 samples)  
 (Indicative Analysis)

Tonnage	% Moisture	%Ni	%MgO	%S	%Fe	As(ppm)	Cl(ppm)	%Co	%SO <sub>2</sub>	%Cu
500	6.89	23.12	8.40	26.80	26.80	129	280	0.60	5.70	0.09
500	6.66	22.71	8.50	26.50	26.50	123	266	0.61	5.70	0.09
500	6.73	24.27	9.60	26.90	26.70	114	272	0.61	6.50	0.08

TABLE 2

## Typical Laterite Analysis

	NiO	Fe2O3	MgO	Co3O4	Cr2O3	MnO	CaO	Al2O3	TiO2	SiO2	LOI	P2O5	SO3	Na2O
Average Limonite Ore	2.05	63.92	1.63	0.15	1.73	1.25	0.01	5.54	0.04	5.52	15.65	0.12	0.73	0.14
Average Transition Ore	3.16	21.50	19.00	0.17	0.57	0.46	0.16	1.46	0.02	38.60	13.30	0.08	0.17	
Average Sappolitic Ore	3.19	16.48	24.16	0.09	0.35	0.29	0.15	1.21	0.01	38.61	14.71	0.06	0.12	

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Where the minerals used for the mineral feeds processed according to the invention include copper levels above those preferred, the minerals may be subjected to a pre-processing step to assist in the removal of copper. The pre-processing step may include flotation.

The mineral feed may also be subjected to other pre-processing steps to remove other unwanted materials. Such pre-processing steps may include flotation to produce a mineral feed enriched in nickel. Another pre-processing step may include drying and/or calcining to drive off sulphur and water. Suitably the calcining may be carried out in a fluidised bed roaster or rotary kiln. Fine dust enriched in nickel may be retrieved from stack gas emanating from the roaster or kiln and mixed with the mineral feed. The fine dust may be mixed in suitable proportions with the mineral feed and fed to a bath smelter or it can be fed dry directly to the smelter via tuyeres using oxygen and/or air and/or nitrogen or other suitable gas to blow the fine dust.

The process of the invention may be carried out in a bath smelter such as a Romelt, Vanukov or Ausmelt smelter. A bath smelter may operate intermittently or continuously by introducing mineral feed and other materials into the furnace into the molten metal and/or foaming slag. It can operate in an oxidation or reduction mode depending on the mix of feeds and energy materials used. In this invention it is operated in the reduction mode to produce ferro nickel, nickel iron ferro chrome steel and/or stainless steel. In a bath smelter conditions are such that the foaming slag may be maintained at a temperature in the range 1300°C to 2000°C, more preferably 1600°C to 1900°C. The slag may be agitated (foamed) by a blast of oxygen, preferably a blast of combustion oxygen injected into the slag by a lower row of tuyeres. This injection also provides primary oxygen for partial combustion of excess carbonaceous material in the slag such as coal or char or coke, to produce principally carbon monoxide. The coal or char or coke may be fed directly into the furnace with the mineral feed. The rate of injection of oxygen and carbonaceous material may be adjusted to control the proportions of iron and nickel metal produced in the slag layer. There must be a surplus of carbon if all the iron is to be reduced to metal, but there can be less carbon if only the nickel is to be reduced with the balance of iron ore remaining in the slag. As nickel ores generally reduce in preference to iron ores, a relatively lower injection of coal and oxygen will result in a metal product containing more nickel than would occur with a relatively higher rate of oxygen injection. Typically, the ratios of nickel to iron will be adjusted to fall within the range 20 - 45% Ni to 80 - 55% Fe for ferro nickel and 10 - 15% Ni to 90 - 85% Fe for nickel iron and 70 - 75% Fe for stainless steel by adjusting the components of the feed and the rate of injection of oxygen and carbonaceous material into the slag layer.

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A secondary upper row of tuyeres may be used to inject combustion oxygen for post combustion of gases exiting from the slag surface. The agitation caused by the injection of combustion oxygen in the fluid slag bath and the fine particles of ore and carbonaceous material assist in creating a tremendous surface area to assist the rate of reduction of iron and also promotes slag turnover for capture and return of a significant proportion of the post combustion heat to the process under reducing conditions. The higher slag temperatures also assist the rate of reduction

A layer of slag below the lower row of tuyeres will be relatively calm. In this relatively calm region, metalised droplets of product separate from the slag layer to drop to the bottom of the furnace. Metal and metal alloys and slag are continuously or intermittently tapped from the furnace through siphon ports or other appropriate facilities and mechanisms.

As a bath smelter can be operated at a slight vacuum, the need for special seals or interlocks can be eliminated. Off gases leaving the furnace, usually at a temperature in the range 1500°C to 2200°C, may be used in a waste heat boiler after which they may be directed to a gas cleaning facility. The off gases can also be combusted with air before or after use in the waste heat boiler. The waste heat can be used to produce steam and hence electrical power of sufficient quantity for the manufacture of oxygen and the power needs of the bath smelter and the excess possibly for export power or additional processing.

The surplus power produced may also be used to reduce chromite in a conventional electric furnace. The ferro chrome so produced can then be mixed with the ferro nickel and/or nickel iron to produce stainless steel in a convertor and/or AOD furnace. The ferro chrome could also be refined in convertors and sold separately with ferro nickel, and or nickel iron as ferro chrome.

Metal alloy produced by the process, may be granulated using the granulation technique described in Applicant's Australian Provisional Application PN6247 filed on 30 October 1995. The process described in said specification for granulation of steel, is applicable to the metal produced by Applicant's invention even if it is essentially in the form of an iron rather than a steel product.

The crude metal alloy produced according to Applicant's invention may be granulated or cast into slabs billets or hot rolled coil immediately subsequent to being produced under reducing conditions, or it may be granulated or cast into slabs billets or hot rolled coil after any subsequent treatment step. For example, the crude metal produced by Applicant's process may be refined in converters and/or an AOD furnace to produce stainless steel which may then be granulated in accordance with the disclosures in the specification for Application PN6247.

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The metal alloy products of the invention may typically be nickel iron, ferro nickel, ferro chrome or crude stainless steel. It may include amounts of chromium and/or cobalt and other minor impurities of other base metals and precious metals. The metal alloy products may be subjected to further processing to produce a refined stainless steel product. The slag produced by the reduction process may be suitable as an aggregate for use in road-making, cement or other pozzolanic application, particularly if subjected to dry cooling processes.

The process may be suitable for treatment of feeds having undesirable arsenic and/or selenium levels as it is anticipated that a substantial proportion of the arsenic and/or selenium will report to the flue gas emanating from the process and also to the discard slag.

Waste process heat emanating from the bath smelter may be used to generate some or all power and/or steam as required for the operation of the process and the manufacture of required oxygen and any surplus used for export power.

In a further aspect the invention provides installations for carrying out the process of the invention.

In a still further aspect the invention provides metal product which has been produced in accordance with the process of the invention.

**Preferred embodiments of the invention**

Preferred embodiments of the invention will now be described with reference to the accompanying drawings.

**Brief description of the drawings**

Figure 1 shows a flow chart of a process in accordance with the invention;

Figure 2 illustrates a flow chart of a process which may be added at the end of the process shown in Figure 1.

Figure 3 illustrates an alternative flow chart of a process which may be added at the end of the process shown in Figure 1.

Figure 4 illustrates an alternative flow chart of a process which may incorporate an additional process step for preparation of the mineral feed.

Figure 5 illustrates an elevational cross section of a typical Romelt smelter.

Figure 6 illustrates a phase diagram of the system MgO-SiO<sub>2</sub>.

Figure 7 illustrates a phase diagram of the systems alpha AL<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub>.

**Detailed description of the preferred embodiments**

Referring to Figure 1, there is shown a flow chart generally designated 1 for carrying out a process according to the invention utilising a bath smelter.

A fluidised bed dryer and/or roaster 4 is provided with a series of air lines 5 for blasting hot air or a hot combustion gas upwards through the bed to cause continuous

## 13.

agitation of mineral feed which has been introduced into the fluidised bed dryer and/or roaster from one or more of the hoppers 10-14. Alternatively a rotary kiln could be used both with respect to drying and/or roasting. The hoppers 10 to 14 may have different mineral feed compositions where blending of the mineral feed is required. Typical sulphur based feed compositions are those shown in Table 1 and laterite compositions in Table 2. The offtake rates from the hoppers 10-14 may be adjusted to give a mineral feed blend which falls within desired parameters for the most efficient operation of the process. After drying or roasting the feed is stored in hopper 4A.

Offtake gas and fines from the fluidised bed roaster are fed through the cyclone scrubber 6 or other equipment (e.g. electrostatic precipitator) which removes the fines and transports them to the fines bin 8.

The scrubbed gas, rich in sulphur dioxide, is fed to the acid production facility 7 where it may be subjected to further combustion with air from the air line 15 in the presence of a catalyst and mixed with water introduced by line 16 to produce sulphuric acid.

Sulphuric acid is removed through the acid offtake 17 and the residual gas is vented through gas vent 19.

Fines which have been transported to the fines bin, may ultimately be recycled directly into the bath smelter 18 or may be stored in a material hopper 8A ready to be introduced into the smelting furnace 18 when needed or may simply be sent to waste.

The bath smelter may suitably be operated under a slight vacuum, preferably about 2.5mm of water column for a Romelt Smelter. Other conditions may be appropriate for other types of smelters.

A number of material hoppers 4A, 8A and 20-25 are arranged to feed dry materials into the bath smelter 18 as and when required. A more detailed view of a typical bath smelter is described hereinafter with reference to Figure 5. Typically, the hoppers may include mineral feed (hopper 4A), fines (hopper 8A), calcined concentrate (hopper 20), chromite (hopper 21), iron ore (hopper 22), recycled dust from the smelter (hopper 23), calcined limestone and/or other suitable flux such as dolomite etc. (hopper 24) and coal and/or char (hopper 25).

Material from the hoppers is fed directly into the bath smelter to fall or be fed directly into a layer of agitated slag and become mixed therein by agitation produced by gases fed into the slag.

The bath smelter 18 is provided with lower and upper tuyeres 29 and 30 respectively. Whilst the tuyeres shown in this drawing illustrate through the smelter wall feeding of oxygen, it is to be appreciated that other arrangements for feeding oxygen to the slag layer and above the slag layer are possible.

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The lower tuyeres are arranged to blast oxygen enriched air into the slag to generate a bubbled slag layer in the form of a slag/gas emulsion, the upper level of the slag gas/emulsion being designated by the broken line 42. The broken line 43 designates the dividing line between the metal/gas/slag emulsion and the relatively quiescent slag below the lower tuyeres 29. Metal droplets including metal alloys formed during the process gravitate downwards through the quiescent slag to fall into the pool of molten metal beneath the slag/metal interface line 44.

The amount of oxygen enriched air injected through the lower tuyeres 29 is adjusted to ensure that there is partial combustion of carbonaceous material which has been introduced into the smelter and into the slag/gas emulsion layer. Thus, the gas/materials mix in the foamed slag layer is maintained under reducing conditions with mainly carbon monoxide being formed but other gases such as hydrogen or carbon dioxide may also be present in relatively smaller quantities.

The mainly carbon monoxide gas then gravitates to the upper part of the smelter where it reacts with oxygen introduced through the upper tuyeres 30 via the oxygen line 27. Sufficient oxygen and carbon is introduced to provide the desired amount of post combustion principally CO to CO<sub>2</sub> to maintain the reactants at the desired temperature. Typically 30% to 60% of the heat generated is reflected into the slag to provide the additional energy required to promote the endothermic reduction of metal oxides to metal and/or alloy.

Very hot off gas from the bath smelter is fed into the burner 45 and may be reacted with more air supplied by the air line 46 to complete combustion.

Very hot gas from the burner 45 may then be transferred to a waste heat boiler 48 and used to generate steam which may be fed by the steam offtake 49 for plant oxygen production or the other uses to an electrical power generation facility for plant or other use and for oxygen production and to supply process heat for other requirements. Excess heat generated in any other stage of the process may be similarly channelled to supply process heat and generate power or used as required. It is anticipated that the bath smelter can provide another source of excess heat (e.g. via dry air slag cooling).

An electrostatic precipitator 51 or other suitable equipment, is arranged to collect dust from off gases and this dust is mixed with dust coming from the waste heat boiler 48 in the dust collector 52 and recycled to the dust collection hopper 43 for eventual return to the bath smelter or for dumping as waste.

Cleaned gas is finally vented through the gas stack 53.

Liquid metal including ferro nickel, nickel iron and stainless steel may be removed from the bath smelter by the metal siphon 40 and similarly slag may be removed by the slag siphon 41. The term liquid metal as used herein includes metal alloys.

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Removal of metal and slag may be continuous or intermittent depending on the particular requirements of the facility concerned.

The slag from slag siphon 41 may be granulated in order to make it suitable for use in applications such as road-making.

Crude liquid metal from the metal siphon may be granulated or cast into slabs or billets or may be subjected to further converting and refining and processing as described below.

Referring to Figure 2, metal including ferro nickel, nickel iron or stainless steel produced by the process described with reference to Figure 1 is fed directly into an oxygen convertor and/or argon, oxygen decarburiser 71 where it is refined using oxygen from oxygen supply 72 and other gases to convert the molten stainless iron metal to stainless steel. Other additions such as chromium metal or charge chrome, or chromite may be added to the molten stainless iron metal in the convertor. The chromium metal or charge chrome (ferro chrome) may be produced by smelting chromite mixed with coke, silica and lime in an electric furnace and fed directly in molten form to the oxygen smelter or oxygen convertor and/or argon oxygen decarburiser.

The stainless steel produced in the convertor and/or argon oxygen decarburiser is then fed to a granulator 73 as described in Applicant's Provisional Application PN6247 and the resultant granules are fed to the cooler 74 where they are treated with an antioxidant spray supplied by the supply line 75 to produce a granulated stainless steel product.

In the alternative arrangement shown in the flow chart of Figure 3, molten metal via by the line 40 is fed directly into a granulator 73 after which the granules are cooled in the cooler 74 and may be treated with antioxidant to produce a ferro nickel product or it may be a granulated nickel iron. Depending on the processing conditions achieved in the bath smelter and/or the electric furnace and the metal composition of the ferro nickel product, the product may even be a form of stainless steel in granulated form or cast product being a slab or hot rolled coil.

As can be seen from the foregoing, because the process of the invention in the embodiments described with reference to Figures 1 to 3 avoids the need for any hydrometallurgical steps. It may result in the production of a useful slag product and has fewer steps than the hereinbefore described conventional processes. It makes use of iron contained in mineral feeds as well as minimising arsenic and selenium contaminates. It can provide the energy for the generation of the power and oxygen requirements of the process and also avoids the use of an electric arc furnace for the production of stainless steel. Thus there are substantial advantages in Applicant's process compared with the conventional processes. The fact that the process can lead directly to the production of a

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readily transportable granulated product or cast slab or billet or hot rolled coil of stainless steel is a further advantage of Applicant's process.

The present invention is therefore considered to provide a cost effective alternative to the conventional processes for the manufacture of ferro nickel, iron and nickel bearing stainless steel products.

Referring to Figure 4, there is shown a flow chart for combining a leach residue with a calcined nickel concentrate to produce a feed suitable for smelting in a bath smelter as described in the preceding examples.

Nickel laterite ore or concentrate, is fed to a leach vessel 80 which is maintained under superatmospheric pressure. The laterite is leached with sulphuric acid and the pressure is maintained at a level which prevents excessive solution of any iron or alumina ores. The pressure leaching produces a solution containing a solution of nickel and cobalt and a residue rich in iron and containing some residual nickel.

The residue is separated from the solution dried and stored in a holding facility 52 from which it may be fed directly into the bath smelter 84.

A dried and/or calcined nickel concentrate from the source 86 may also be added to the total mineral feed fed to the bath smelter. In addition, process dust arising from the overall processing of the various steps in the flow chart (not shown here but shown with reference to Figure 1) may also be added to the mineral feed from the process dust holding bin 88. The relative levels of feeds from the various sources 80 to 86 and 88 may be adjusted to provide a satisfactory proportion of nickel in the mineral feed while ensuring that undesirable materials such as copper or cobalt are maintained below predetermined limits. Nickel metal may also be added.

Molten metal containing iron and nickel is fed directly from the bath smelter into the convertor 94 and/or argon oxygen decarburiser where it is combined with pure nickel and/or other metal feeds such as ferro-chromium, iron or steel or other ferro nickel alloy.

In the illustrated embodiment, the leachant solution rich in nickel and cobalt from the leach vessel 80 is transferred to a facility 90 such as a solvent extraction and electrowinning plant or other hydrometallurgical processes which is used to separate metals such as nickel and cobalt, transferring them to the holding facility 92, with residues being discarded via a discharge line 91.

Cobalt may be discharged to a storage facility 93 whilst the nickel may be added directly to the convertor 94 and/or argon oxygen decarburiser in which the iron/nickel metal mix is converted to stainless steel.

Exhaust gases 95 may be used to supply process heat requirements and to generate electricity.

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The molten austenitic (nickel bearing) stainless steel may be discharged via the line 96 to be cast as slabs, billets, hot rolled coil or other suitable products or to be granulated in the manner described hereinbefore.

Referring to Figure 5, there is shown a typical smelter construction 50 lined with different specialised refractories 51 making up the hearth roof and walls of the furnace. Cooling panels 52 such as water cooled copper panels are provided in the walls. Using cooling panels to line the wall in the region of the bubbled slag, means that there are no refractories directly exposed in this region. The cooling panels act to freeze the slag at the surface of the panels thereby providing a non reactive refractory lining which is the slag of the slag layer. Because the smelter will typically be operated at very high temperatures (say 1800°C) the choice of suitable refractories which can withstand such aggressive conditions is very limited and expense associated with using such refractories can be very high. The use of cooled panels in this region of the furnace can therefore provide substantial advantages.

Mineral feed and coal are fed into the smelter via the filling spout 53 provided in the roof of the furnace and combustion gases exit through the gas off take 54. Oxygen enriched air or industrial oxygen 60 is provided through the lower tuyeres 58 and industrial oxygen 61 is provided through the upper tuyeres 59.

The solids in the smelter distribute across three layers. The uppermost layer 57, because it is agitated with combustion gases, includes entrained gases and hence has a "highly agitated" quality. The intermediate layer 56 contains slag and metal droplets. The bottom layer 55 contains a mixture of molten iron and nickel. The bottom molten metal layer may be tapped (not shown) to remove molten metal as required. Similarly the slag layer includes a tapping point (not shown) for removing excess slag.

Whilst it has been convenient to describe the invention herein in relation to particularly preferred embodiments, it is to be appreciated that other constructions and arrangements are considered as falling within the scope of the invention. Various modifications, alterations, variations and/or additions to the constructions and arrangements described herein are also considered as falling within the scope and ambit of the present invention.

**Claims**

1. A method for the reduction of a mineral feed containing a nickel bearing ore and/or concentrate and an iron source in a single smelter to produce a metal alloy product containing both nickel and iron metal including the steps of:-
  - (i) adding the feed to a bath smelter;
  - (ii) forming a slag layer containing carbonaceous material in the bath smelter above a layer of metal alloy product;
  - (iii) bubbling oxygen containing gas directly into the slag layer to form a bubbled region of slag above a relatively calm slag region;
  - (iv) directing oxygen containing gas into the bath smelter above the bubbled slag for post combustion of gases exiting from the slag layer;
  - (v) maintaining reducing conditions in the slag layer whilst causing formation of metal droplets therein; and
  - (vi) allowing the droplets to drop through the slag layer to accumulate as a layer of metal alloy product containing both nickel and iron beneath the slag layer.
2. A method according to claim 1 wherein the mineral feed includes nickel bearing calcined sulphide concentrate and/or a dried nickel bearing sulphide concentrate.
3. A method according to claim 1 wherein the mineral feed includes iron ore, a nickel bearing calcined sulphide concentrate or laterite or mixtures of calcined nickel bearing concentrate and laterite ore.
4. A method according to claim 1 wherein the mineral feed includes chromite and at least one of iron ore, calcined nickel bearing concentrate, and laterite ore, the composition of the feed and conditions in the bath smelter being set to produce a crude stainless steel.
5. A method according to claim 2 wherein the mineral feed includes at least 10% by weight of magnesium compounds.
6. A method according to claim 2 wherein the mineral feed includes a solid oxide and/or carbonate residue derived from leaching a nickel bearing laterite ore.
7. A method according to claim 2 wherein the feed includes at least 8% by weight of nickel.
8. A method according to claim 2 wherein the feed includes a calcined nickel

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sulphide concentrate and a laterite ore wherein the concentration of nickel in the laterite is less than 4% by weight of nickel.

9. A method according to claim 1 wherein the mineral feed includes a chromium source in proportions sufficient to ensure the metal alloy product contains at least 2% by weight of chromium.

10. A method according to claim 9 wherein the chromium source includes at least one of a chrome-iron oxide, laterite chrome, chromium metal, charge chrome, chromite or mixtures thereof.

11. A method according to claim 1 wherein processing additives chosen from limestone, dolomite, flux or silica and/or mixtures thereof are added to the metal feed.

12. A method according to claim 11 wherein the carbonaceous material includes one or more of coal, coke, coal char, petroleum coke or coke breeze.

13. A method according to claim 12 wherein combustion oxygen containing at least 80% oxygen is bubbled directly into the slag layer and is also injected directly into the smelter above the slag layer for post combustion of gases exiting from the slag layer by a plurality of tuyeres.

14. A method according to claim 13 wherein the slag layer is maintained at a temperature in the range 1300°C to 2000°C and the bath smelter is operated under slight vacuum conditions.

15. A method according to claim 1 wherein heated gases emanating from the bath smelter are used to produce steam and electrical power which is in turn supplied to meet the electrical power needs of the bath smelter.

16. A method according to claim 13 wherein the combustion oxygen is bubbled into the slag layer and injected into the region above the slag layer by lower and upper rows of tuyeres extending through parallel sides of the bath smelter.

17. A method according to claim 1 wherein the metal alloy product is granulated.

18. A method according to claim 1 wherein the feed includes arsenic and/or selenium.

19. A method according to claim 1 wherein the metal alloy product is blown with oxygen in a convertor and/or argon oxygen decarburiser to produce stainless steel.

20. A method according to claim 1 wherein the mineral feed includes a leach residue and a nickel bearing calcined sulphide concentrate, the leach residue being the solid product of leaching a nickel laterite ore and/or concentrate with a sulphuric acid leachant under conditions which ensure that the major proportion of any iron ore present in the nickel laterite ore or concentrate does not go into solution.

21. A method according to claim 20 wherein the leachant is subjected to solvent extraction and electrowinning or other standard hydrometallurgical processes to recover

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nickel and cobalt after leaching has been completed.

22. A method according to claim 2 wherein the bath smelter includes walls lined with fluid cooled copper lining panels in the region of the bubbled slag layer.

23. A metal alloy product produced in accordance with the method of claim 1.

24. A method for the reduction of a mineral feed to produce an austenitic stainless steel product including the steps of:-

- (i) calcining a nickel sulphide ore and/or concentrate;
- (ii) forming a blend of said calcined nickel sulphide ore and/or concentrate with a nickel laterite;
- (iii) including said blend in said mineral feed;
- (iv) adding the feed to a bath smelter;
- (v) forming a slag layer containing carbonaceous material in the bath smelter above a layer of molten metal alloy containing nickel and iron;
- (vi) bubbling oxygen containing gas directly into the slag layer to form a bubbled region of slag above a relatively calm slag region;
- (vii) directing oxygen containing gas into the bath smelter above the bubbled slag for post combustion of gases exiting from the slag layer;
- (viii) maintaining reducing conditions in the slag layer whilst causing formation of metal droplets therein;
- (ix) allowing the droplets to drop through the slag layer to accumulate as a layer of molten metal alloy containing nickel and iron beneath the slag layer;
- (x) treating a chromite ore in an electric furnace to produce ferro chrome;
- (xi) combining the ferro chrome and molten metal alloy with ferro silicon and ferro manganese at a refining station; and
- (xii) refining the combined ferrochrome molten metal alloy ferrosilicon and ferromanganese at the refining station to produce austenitic stainless steel.

25. A method according to claim 24 wherein the refining station includes an argon oxygen decarburiser and optionally a convertor.

26. A method for the reduction of a mineral feed to produce an austenitic stainless steel product including the steps of:-

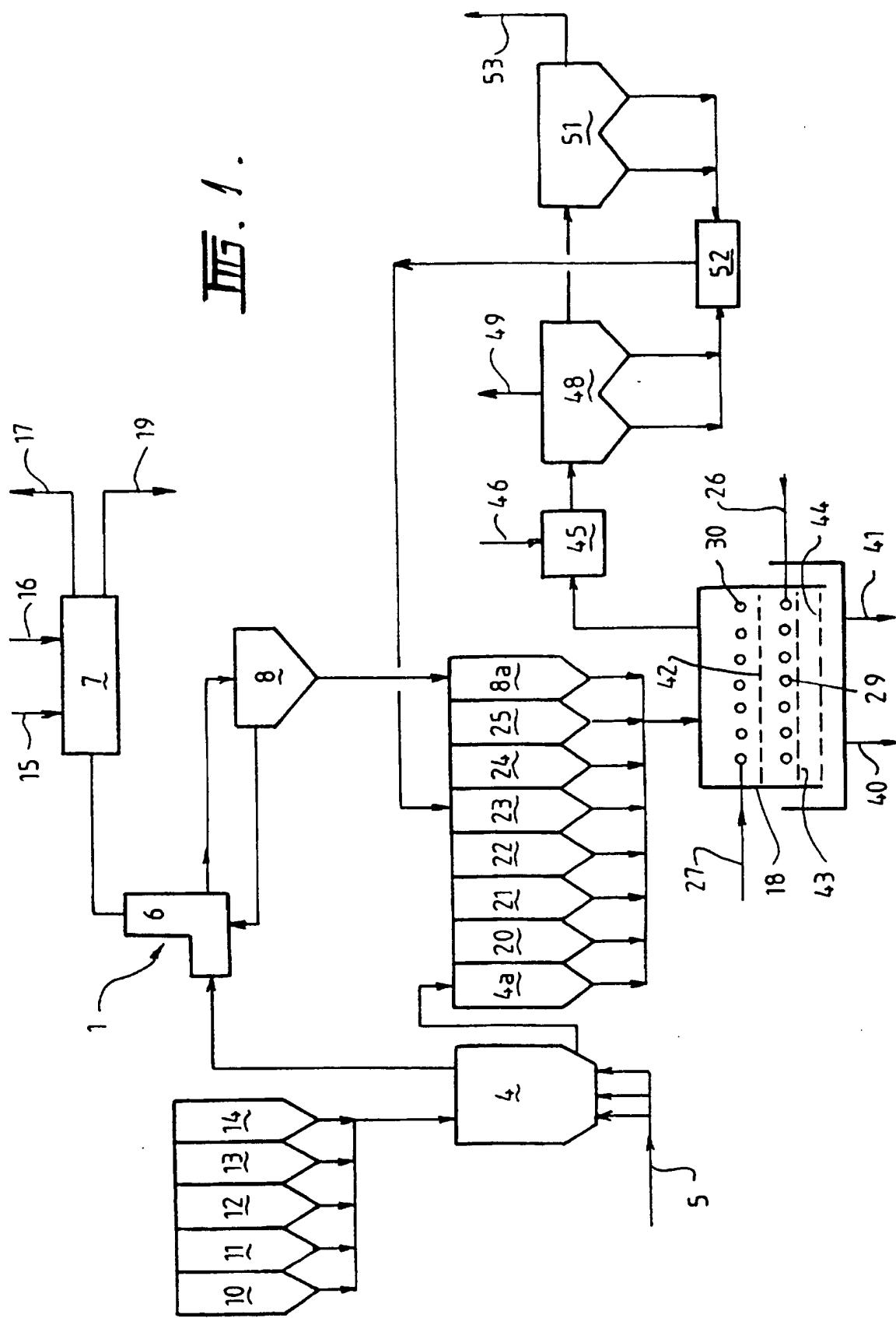
- (i) calcining a nickel sulphide ore and/or concentrate;
- (ii) forming a blend of said calcined nickel sulphide ore and/or concentrate with a nickel laterite;
- (iii) including said blend in said mineral feed;
- (iv) adding the feed to a bath smelter;
- (v) forming a slag layer containing carbonaceous material in the bath smelter above a layer of molten metal alloy containing nickel and iron;

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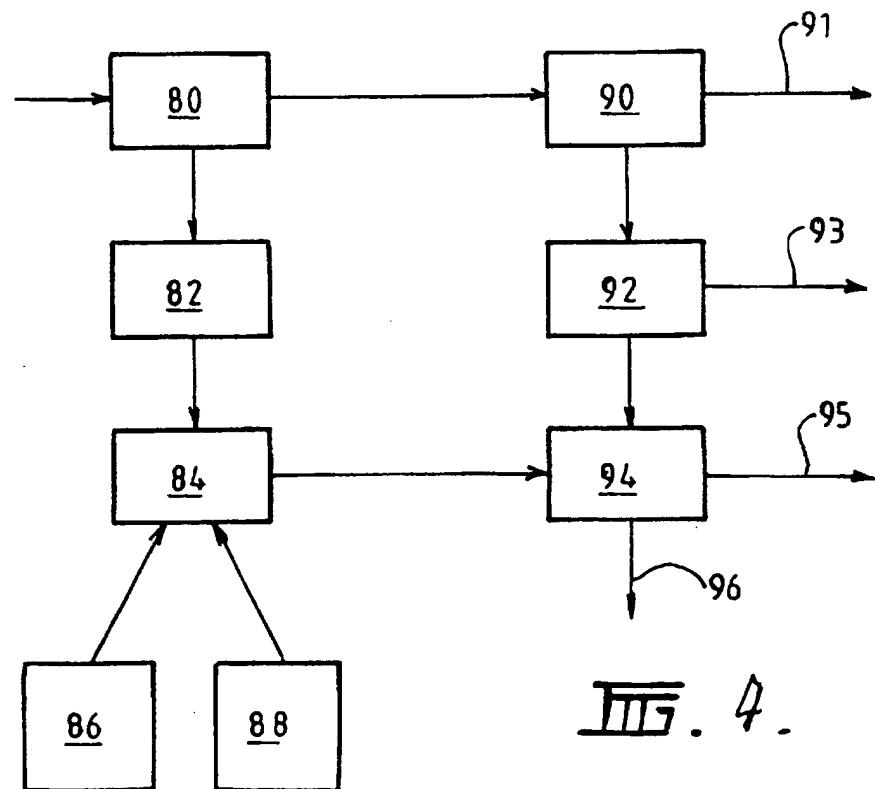
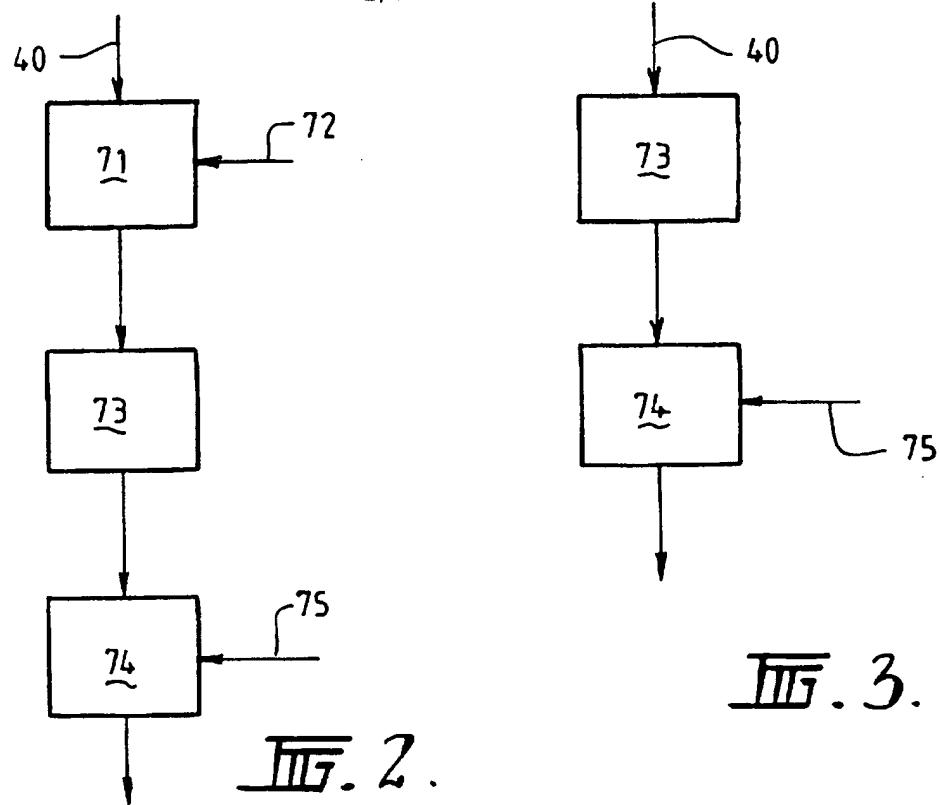
- (vi) bubbling oxygen containing gas directly into the slag layer to form a bubbled region of slag above a relatively calm slag region;
- (vii) directing oxygen containing gas into the bath smelter above the bubbled slag for post combustion of gases exiting from the slag layer;
- (viii) maintaining reducing conditions in the slag layer whilst causing formation of metal droplets therein;
- (ix) allowing the droplets to drop through the slag layer to accumulate as a layer of molten metal alloy containing nickel and iron beneath the slag layer;
- (x) combining the molten metal alloy with ferro silicon and ferro manganese at a refining station;
- (xi) refining the combined molten metal alloy, ferrosilicon and ferromanganese at the refining station to produce austenitic stainless steel.

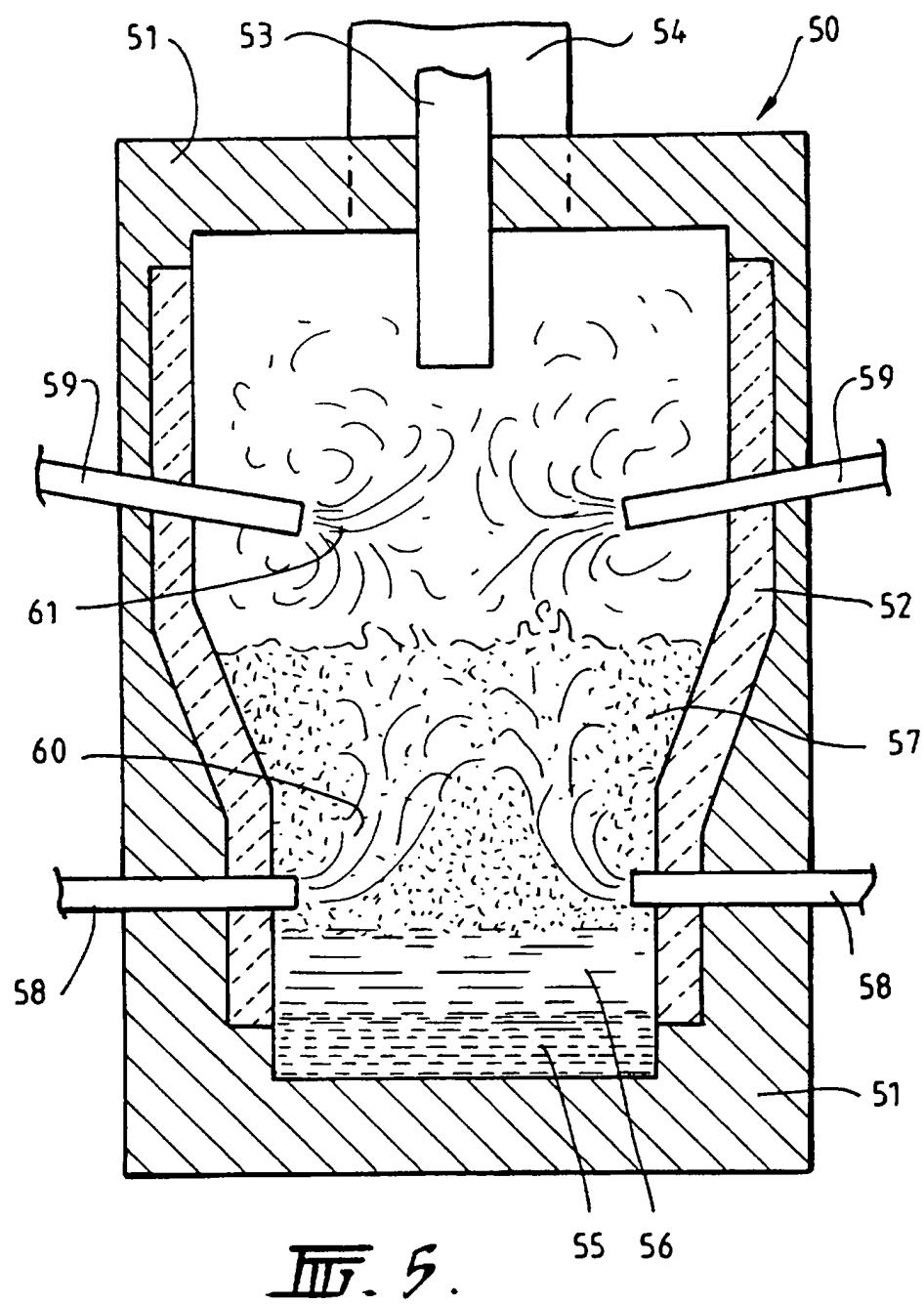
27. A method according to claim 26 wherein the refining station includes an argon oxygen decarburiser and optionally a convertor.

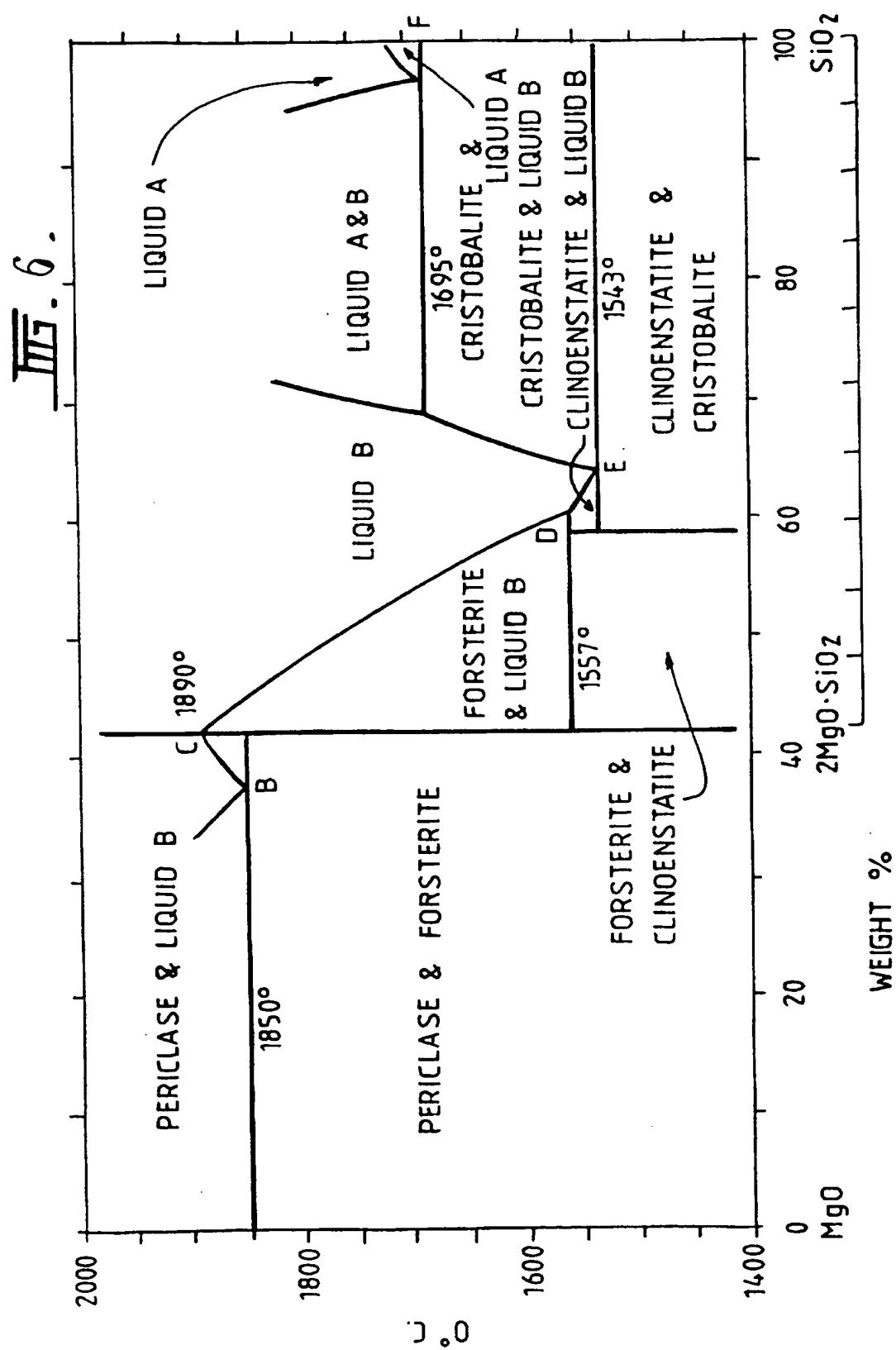
28. A method according to claim 24 wherein waste heat from the bath smelter is used to provide the electrical and heating requirements for operating the steps of the method.



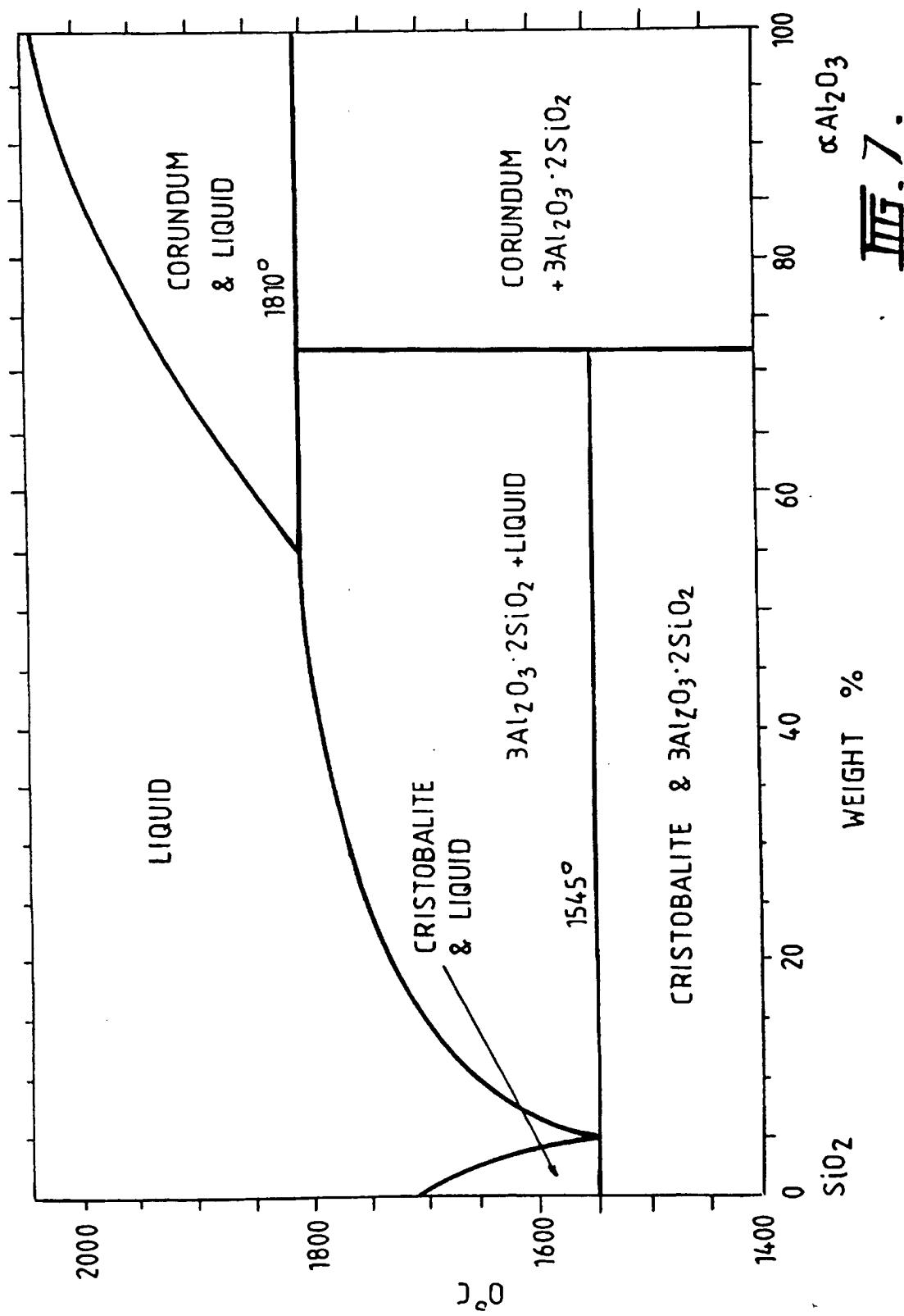
2/5







5/5



# INTERNATIONAL SEARCH REPORT

## A. CLASSIFICATION OF SUBJECT MATTER

Int Cl<sup>6</sup>: C21B 11/08, C22B 5/10, 5/12, 23/02, C22C 35/00, 37/00, 37/08 ||  
 C01B 17/52, 17/56, C21C 5/32, 5/34, 5/35, C22B 34/32, 4/06,  
 C22C 38/08, 38/40, B03D 1/08, F26B 3/08, C22B 1/10.

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC : C21B 11/, C22B 4/, C22B 5/, C22B 23/, C22B 34/32.

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched  
 AU : IPC as above.

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

See attached listing.

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	Derwent Abstract Accession No. 80-41643C/24, Class M25 <b>DE 2851098 A1 (MOSCOW STEEL ALLOYS INSTITUTE)</b> , 4 June 1980	1-28
A	<b>EP 137913 A1 (OLIN CORPORATION)</b> , 24 April 1985, (see page 5 line 1 to page 8 line 10 and Figure 1 of the drawings).	1-28
A	<b>EP 386407 A2 (NKK CORPORATION)</b> , 12 September 1990, (see page 2 line 27 to page 5 line 10 and Figures 1, 2 and 3 of the drawings).	1-28



Further documents are listed in the continuation of Box C



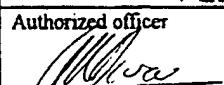
See patent family annex

• Special categories of cited documents:		
"A" document defining the general state of the art which is not considered to be of particular relevance	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"E" earlier document but published on or after the international filing date	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O" document referring to an oral disclosure, use, exhibition or other means	"&"	document member of the same patent family
"P" document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search  
 24 January 1997.

Date of mailing of the international search report  
 27 FEB 1997

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## INTERNATIONAL SEARCH REPORT

International Application No. PCT/AU 96/00766
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C (Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	<b>FR 2619825 A1 (HYUGA SMELTING CO. LTD.)</b> , 3 March 1989, (see page 7 line 21 to page 11 line 30 and Figures 1 and 2 of the drawings).	1-28
A	Derwent Abstract Accession NO. 88-032109/05, Class M27 (M24) <b>JP 62/290843 A2 (NIPPON KOKAN K.K.)</b> , 17 December 1987	1-28
A	Patent Abstracts of Japan, C-780, page 54, <b>JP 02/221309 A2 (SUMITOMO METAL INDUSTRIES LTD.)</b> , 4 September 1990.	1-28
A	<b>WO 91/05879 A1 (AUSMELT PTY. LTD.)</b> , 2 May 1991, (see page 10 line 9 to page 19 line 24 and Figures 1, 2, 3 and 4 of the drawings).	1-28

# INTERNATIONAL SEARCH REPORT

International Application No.

PCT/AU 96/00766

## Box B FIELDS SEARCHED continued

### DEMENT:

IC: (C21B-11/ + C22B-4/ + C22B-5/ + C22B-23/ + C22B-34/32)

AND

(NICKEL: + NI)

AND

(IRON + FE + FERR: + STEEL + SCRAP)

AND

(ORE + CONCENTRATE + CHROMITE + LATERITE + OXID: + CARBONAT: + SULPHID: + SULFID: + PYR:

AND

(SMELT: + MELT: + MOLT: + FUS: + LIQU:)

### JAPIO:

IC: (C21B-11/ + C22B-4/ + C22B-5/ + C22B-23/ + C22B-34/32)

AND

(NICKEL: + NI)

AND

(IRON + FE + FERR: + STEEL + SCRAP)

AND

(ORE + CONCENTRATE + CHROMITE + LATERITE + OXID: + CARBONAT: + SULPHID: + SULFID: + PYR:

AND

(SMELT: + MELT: + MOLT: + FUS: + LIQU:)

**INTERNATIONAL SEARCH REPORT**  
Information on patent family members

International Application No.  
PCT/AU 96/00766

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report				Patent Family Member			
DE	2851098 A1	DE	2851098 C2				
EP	137913 A1	CA	1223744 A1	JP	60043420A2	US	4472195 A
EP	386407 A2	AU	47760/90 A1	AU	624893 B2	BR	9001096 A
		CA	2011702 AA	CA	2011702 C	CN	1045423 A
		CN	1021348 B	DE	69018500T2	EP	386407 B1
		JP	2236235 A2	JP	7091600 B4	KR	9301130 B1
		US	5047082 A				
FR	2619825 A1	FR	2619825 B1	JP	1062438 A2	JP	1051534 B4
JP	62290843A2	JP	4030456 B4				
JP	2221309 A2						
WO	9105879 A1	AU	65078/90 A1	AU	633153 B2		
END OF ANNEX							